**Economic Assessment of the Viability of Advanced Ultra-Super Critical Coal-Fired Power Plants**

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**Executive Summary**

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**7. Methodology**

**Materials selection process - Bri/Kelly**  
            For each component within each of the two condition categories (HP/IP and LP) there is a three-phase process that the group of possible materials will be taken through.  Phase 1 is the elimination phase where inadequate materials properties automatically disqualify the material from continuing through the selection process.  These properties include creep strength, weldability, and machinability. Phase 2 ranks the materials performance relative to each other to determine the most desirable material to be used for each component. Properties used for this ranking include cost, oxidation resistance, and yield strength. Phase 3 then analyzes the compatibility of the optimal materials for each component in the complete turbine system based on the matching of thermal properties. Materials will be eliminated at each phase if they do not meet the requirements or are on the low end of the ranking scale.  The general outline for the selection process is as follows:  
\*\*FIGURE 7.1

Common aspects of the HP/IP and LP selection processes are adequate weldability and machinability of the materials.  Weldability is essential for all components other than the blades and nozzles because they are connected and repaired through welding.  Blades and nozzles are held into place by a root (see figure ??? in section ???) so weldability is not a factor for these components. Weldability was determined based on the amount of hardening alloying elements including Ti and Al.  The weldability cutoff was set at less than 2.5 wt% Ti + Al.  Machinability of large and irregularly shaped components is also a crucial deciding factor in the use of materials.

Differences in material requirements for the different components and HP/IP and LP turbines stem from the varying temperatures, steam conditions and component functions across the entire turbine (see figure XXX) .  The HP/IP components need to withstand temperatures of 760C and pressures up to 35MPa, while the LP components only experience temperatures around 320C at 0.5MPa.  The components to be analyzed by the HP/IP material selection process includes the HP/IP rotor, HP/IP diaphragm, HP/IP blades and nozzles, and the entire inner casing since it will be made out of a single material that needs to withstand the most extreme conditions. The extreme steam conditions in the HP/IP component where the steam enters directly from the boiler necessitates a significantly high creep rupture strength, leading to the requirement of a Larson-Miller parameter of 25,000 or higher at 100MPa.   Components to be analyzed through the LP materials selection process include the LP rotor, LP diaphragm, and LP blades and nozzles.  Meeting the criteria of a Larson-Miller parameter is not applicable for Phase 1 of the LP components, since creep is not a likely mode of failure at those temperatures and pressures.

The ranking of materials in phase 2 is based on the normalized cost of materials with consideration to oxidation resistance. The materials analyzed in phase 2 have adequate mechanical properties to perform the general function required for each component, so desirability can be ranked primarily on an economic basis. An alloy with a higher yield strength requires less material to be used to build the component with appropriate strength. Therefore, cost of each alloy can be normalized by dividing the cost per weight by the yield strength. This property is optimized where $/σy is minimized resulting in the lowest cost to achieve adequate strength. Oxidation is considered where $/σy is within 10% of other alloy values as a second tier ranking mechanism.

The different selection methods are outlined in the table to show how each component in each steam condition is assessed.

\*\*TABLE 7.1

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *Phase 1*  *Phase 2*  *(in order of importance)* | HP/IP | | | LP | | |
| Rotor/diaphragm | Blades/nozzles | Casing | Rotor/diaphragm | Blades/nozzles |  |
| LMP ≥ 25  Weldable  Machinable | LMP ≥ 25  \*does not need to be  weldable  Machinable | LMP ≥ 25  Weldable  Machinable | LMP N/A  Weldable  Machinable | LMP N/A  \*does not need to be weldable  Machinable |  |
| YS  Cost  Oxidation | YS  Cost Oxidation | YS  Cost  Oxidation | YS  Cost  Oxidation | YS  Cost  Oxidation |  |

\*\*FIGURE 6.1

After selecting a material for each component within both the HP/IP turbine and the LP turbine we will look at the entire turbine together to assess the economic feasibility.  The entire process is described in the following diagram:

\*\*FIGURE 7.2

**8. Findings to Date – Results of Materials Selection Process**

List of potential materials: HP/IP Components  
Nimonic 105  
Nimonic 115  
Haynes 230  
Nimonic 263  
Haynes 282  
Inconel 617  
Inconel 625  
Inconel 718  
Inconel 740  
Waspaloy  
U720  
X U700  Eliminated due to lack of available data  
X U710  Eliminated due to lack of available data  
X ODS-FeCrAl  Eliminated due to lack of available data  
  
List of potential materials: LP components  
316Ti Stainless  
304 Stainless   
253MA  
A286

Within the HP/IP materials selection process, the blade and nozzle material are determined separately from the rotor, diaphragm and casing material. Phase 1 of the HP/IP rotor, diaphragm and casing material includes a weld criterion while the blades and nozzles do not. Materials with a Ti + Al content of less than 2.5 wt% meet this weld criteria. For all HP/IP components, the Larson-Miller parameter must be greater than or equal to 25,000 at 100MPa, which represents 100,000 hours at operation temperature of 760C. An expert was consulted to determine machinability of each material. In this case, all materials which passed the weld and creep criteria also passed the machining criterion. The process and resultant candidate materials of phase 1 for the HP/IP rotor, diaphragm, and casing are shown in Figure 8.1. The three final materials, Inconel 617, Inconel 740 and Nimonic 263, then move on to phase 2 for the HP/IP rotor, diaphragm, and casing material. The properties and calculations considered in phase 2 for the HP/IP rotor, diaphragm and casing are shown in Table 8.1. Inconel 740 is clearly the optimal choice of material for the HP/IP rotor, diaphragm, and casing components.

This process is reiterated for the HP/IP blade and nozzle materials with the exclusion of the weldability requirement. As seen in Figure 8.2, without the limitation of the weldability, 7 materials pass through phase 1 into phase 2 including Inconel 617, Inconel 740, Nimonic 263, Nimonic 105, Nimonic 115, Waspaloy, and Haynes 282. In phase 2 (table 8.2), Nimonic 105, Nimonic 115, Waspaloy, and Haynes 282 have comparably low $/σyvalues, however Nimonic 105 and Nimonic 115 are chosen as the optimal materials as they have a much higher oxidation ranking than Waspaloy and Haynes 282.

The LP component selection process is outlined in Figure 8.3 and Table 8.3. Phase 1 for the LP rotor, diaphragm, blades and nozzles did not disqualify any of the proposed materials for the lower pressure, lower temperature applications. Since they are austenitic steels, all candidate materials are readily weldable and machinable. The Larson-Miller requirement is not applicable in these conditions since the required parameter value is incredibly low in comparison to the parameter value the materials contain at these temperatures and pressures. Phase 2 ranks the steels by cost per unit strength to give A286 as the optimum.

\*\*FIGURE 8.1 - Phase I: HP/IP Components – Rotor, diaphragm and casing



\*\* TABLE 8.1 - Phase II: HP/IP Components – Rotor, diaphragm and casing



\*\*FIGURE 8.2 - Phase I: HP/IP Components – Blades and Nozzles



\*\* TABLE 8.2 - Phase II: HP Components – Blades and Nozzles



\*\*FIGURE 8.3 - Phase I: LP Components – Rotor, Diaphragm, Blades and Nozzles



\*\* TABLE 8.3 - Phase II: HP Components – Rotor, Diaphragm, Blades and Nozzles



Appendix

